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PLOMIN, ROBERT, and DEFRIES, J. C. *The Colorado Adoption Project*. CHILD DEVELOPMENT, 1983, **54**, 276–289. This report provides an overview of the Colorado Adoption Project (CAP), a longitudinal, prospective, multivariate adoption study of behavioral development. Examples of the types of analyses that can be conducted using this design are presented. The examples are based on general cognitive-ability data for adoptive, biological, and control parents; assessments of their home environment; and Bayley Mental Development Index scores for 152 adopted children and 120 matched control children tested at both 1 and 2 years of age. The illustrative analyses include examination of genetic and environmental sources of variance, identification of environmental influence devoid of genetic bias, assessment of genotype-environment interaction and correlation, and analyses of the etiology of change and continuity in development.

Marie Skodak and Harold Skeels's (1949) report of a longitudinal adoption study of IQ is one of the most frequently cited articles in developmental psychology. The IQ scores of adopted children tested four times between infancy and adolescence were compared to characteristics of both their adoptive parents and their biological parents. The results of the study were impressive: the correlation between the IQ of 63 biological mothers and their adopted-away children indicated increasing hereditary influence during childhood and reached .45 when the children were adolescents.

Despite the interest in this adoption study, 25 years elapsed before the adoption design was again employed to study development. During the past 5 years, however, IQ data have been reported for 2,540 pairings in studies that used the adoption design. Two of the largest studies (Horn, 1983; Scarr & Weinberg, in this issue) are described in this volume. The results of these studies converge on the conclusion that individual differences in IQ are substantially influenced by genetic differences among individuals, and that family environment also has a significant impact. These data are consistent with the results of other behavioral genetic research in suggesting that genetic factors account for about 50% of the variance in IQ scores, and that shared family environmental factors account for about 15% of the variance, although shared family environment may be more influential early in development and less influential later (Plomin & DeFries, 1980).

General acceptance of the idea that individual differences in IQ are substantially shaped by genetic differences among individuals is due in large part to the convincing evidence provided by adoption studies. However, there is much more that adoption studies can do than merely document genetic influence on IQ. Behaviors other than IQ can be studied in their own right and in their interaction with cognition. The inclusion of environmental measures within an adoption design provides the opportunity to assess environmental influences free of genetic bias. These environmental assessments also permit the isolation of specific genotype-environment interaction and correlation (Plomin, DeFries, & Loehlin, 1977). Furthermore, longitudinal adoption studies can be designed to assess the etiology of change and continuity in development (Plomin & DeFries, 1981).

In 1975, the Colorado Adoption Project (CAP) was initiated to investigate genetic and environmental influences on behavioral development. The purpose of this article is to present an overview of the CAP and to discuss the results of analyses of CAP cognitive measures and environmental assessments as examples of the types of information that can emerge from a design of this sort.

Method

The CAP is a longitudinal, prospective, multivariate adoption study of behavioral development. It is a "full" adoption design in that a test battery is administered both to

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adoptive parents and to biological parents of the adoptees (DeFries & Plomin, 1978). The adoptees are placed in their adoptive homes in the first month of life and have no contact with their biological parents after placement. They are tested in their adoptive homes at 1, 2, 3, and 4 years of age. In addition, "control" (nonadoptive) families are matched to the adoptive families and studied in the same manner. The gist of this adoption design is simple. In control families, observed relationships between measures on parents and offspring (or between environmental indices and offspring measures) may be mediated genetically as well as environmentally. The adoption design neatly cleaves these two major classes of developmental influence by permitting study of resemblances between parents and children who share only postnatal family environment (adoptive parents and adoptees) and of resemblances between parents and children who share heredity but no postnatal environment (biological parents and their adopted-away children). Younger siblings of the adopted and nonadopted probands are studied in the same manner as the probands in order to obtain a sample of unrelated children reared together and a comparison group of genetically related siblings. Details of the CAP design, including a discussion of the effects of selective placement and assortative mating, can be found elsewhere (DeFries, Plomin, Vandenberg, & Kuse, 1981).

Sample

More than 200 adoptive families and nearly 200 control families are now participating in the CAP, and families are still being added. The oldest children are 6 years old. In this section, we shall briefly describe subject selection and the representativeness of the sample.

Biological parents are solicited through two Denver adoption agencies. Seventy-two percent of the biological mothers are tested while pregnant, and a concerted effort is made to test biological fathers. Although only 20% participate, this is the first time that any tests have been administered to biological fathers in an adoption study. For the adoptive parents, the average time from first contact with the agency to placement of an "easily placed" child (Caucasian neonate with no known disabilities) is approximately 3 years. The control families are matched to the adoptive families on the basis of sex of proband, number of children in the family, age of father (± 5 years), occupational status (± 8 NORC points), and total years of the father's education (± 2 years). Over 95% of the CAP adults regard themselves as being Caucasian.

Because of such stereotypes as "adoptive parents come from the upper class" and "biological parents are from the lower class," it is reasonable to question the representativeness of adoption-study samples. Occupational status is one way to address this issue. The CAP has used the NORC (National Opinion Research Center) occupational prestige ratings of Duncan (in Reiss, Duncan, Hatt, & North, 1961) as modified in the Hawaii Family Study of Cognition (DeFries, Ashton, Johnson, Kuse, McClearn, Mi, Rashad, Vandenberg, & Wilson, 1976). The same measure of occupational status was employed in an epidemiological study of smoking conducted in the metropolitan area of Denver (Crumpacker, Cederlöf, Friberg, Kimberling, Sörensen, Vandenberg, Williams, McClearn, Grevér, Iyer, Krier, Pedersen, Price, & Roulette, 1979). The latter sample was "selected by a stratified random sampling procedure in suburban Jefferson County, Colorado, using 1970 census data and a 1975 city directory, which referenced households geographically" (p. 183).

Table 1 presents a comparison of the occupational status of the CAP males, and of the fathers of the CAP males and females, to the occupational status of the stratified random sample of Denver males in the smoking study. The CAP data given in the table refer only to parents of the probands included in analyses discussed in this report (i.e., probands who have been tested at both 1 and 2 years of age). The average NORC rating for the adoptive and control fathers is about 75; their fathers' average rating is about 70. Because the biological fathers of the adopted children are only 20 years old on the aver-

TABLE 1

NORC Ratings of Males in the CAP and in the Denver Sample

	Mean	SD	*N*
Biological fathers	61.7	10.9	25
Adoptive fathers	75.7	9.1	144
Control fathers	73.4	9.1	120
Biological fathers' fathers	72.4	8.0	27
Biological mothers' fathers	70.9	10.4	134
Adoptive fathers' fathers	68.0	10.5	117
Adoptive mothers' fathers	70.2	10.2	134
Control fathers' fathers	71.5	9.9	98
Control mothers' fathers	71.9	9.9	101
Denver sample[a]	71.3	7.8	162

[a] From Crumpacker et al. (1979).

age, a lower NORC score is expected. However, the average NORC rating of their fathers and of the biological mothers' fathers is about 72, which is similar to the ratings of the fathers of the adoptive and control fathers. Most important, these mean occupational status ratings are quite similar to that of the stratified random sample of Denver males.

The standard deviations included in Table 1 are particularly informative concerning the issue of representativeness and restriction of range. In every case, the CAP sample has a larger standard deviation than that found for the stratified random sample of Denver males. Thus, contrary to some commonly held notions about biological and adoptive parents, the parents in the CAP represent a broad cross section of the Caucasian population.

Measures

Because of the increase in use of contraception and abortion, it is unlikely that an adoption study of this type can be conducted again in the United States, at least not in the foreseeable future. For this reason, a decision was made at the outset to devise a test battery to sample extensively and broadly rather than intensively and narrowly. An adult test booklet, which takes about 3 hours to complete, is administered to the biological, adoptive, and control parents in small groups. The test booklet includes: demographic items; 16 tests of specific cognitive abilities; self-report and spouse ratings of personality, including Cattell's 16 Personality Factor Test (Cattell, Eber, & Tatsuoka, 1970) and self- and mate-ratings on the EASI Temperament Survey (Buss & Plomin, 1975); mood ratings; items concerning commonly used drugs, interests and talents, and common health and behavioral problems (e.g., headaches, speech problems, phobias); and questions about miscellaneous characteristics such as handedness.

In giving examples of the types of analyses possible using the CAP design, this report will be focused on the cognitive data. As described in a previous publication (DeFries et al., 1981), the median split-half reliability for the cognitive tests is .86 for each of the three types of parents. The median test-retest correlation for a sample of undergraduate students was .80. The factor structure of the tests is robust, yielding the expected specific cognitive-ability factors of spatial ability, verbal ability, perceptual speed, and visual memory, and is highly similar for the three types of parents. The first principal component (unrotated) accounted for 37% of the variance and will be used as a measure of general cognitive ability, or IQ. In a study using similar tests, the first principal component was found to correlate .73 with WAIS full-scale IQ, a correlation that is comparable to reported correlations between WAIS IQ and other standard tests of intelligence (Kuse, Note 1).

Measures for the CAP children are obtained during 2–3-hour visits to the adoptive and control homes. Some information is obtained prior to and after home visits by mail and by telephone interview. Measures at 1 and 2 years of age include the Bayley Scales of Infant Development (Bayley, 1969), which are used to assess mental and motor development and to provide ratings of temperament; four scales of the Uzgiris-Hunt Ordinal Scales of Psychological Development (Uzgiris & Hunt, 1975); the Colorado Childhood Temperament Inventory (Rowe & Plomin, 1977), completed by both mothers and fathers; parental ratings on the nine dimensions of temperament postulated by the New York Longitudinal Study group (Thomas & Chess, 1977); videotaped observations of mothers and infants interacting in standard situations used to rate temperament (Plomin, 1982) and to measure communicative development (Hardy-Brown, Plomin, & DeFries, 1981); and a parental interview and pediatrician's form concerning major health-related aspects of development. Perinatal information is obtained on the infants of the biological and control mothers.

Two major environmental measures are employed. Caldwell and Bradley's (1978) Home Observations for the Measurement of the Environment (HOME), a semistructured interview which has become a widely used measure, is used to evaluate early environmental influences that may affect infant cognitive development. The Family Environment Scale (Moos, 1974), a self-report questionnaire concerning interpersonal relationships and organizational structure of the family, is completed by both parents. Supplementary environmental measures include ratings by the home tester (e.g., "ecological" ratings of the home and neighborhood) and interview questions concerning the accessibility of the parents and the presence of various objects in the home. The videotapes of mother-infant interaction are also used for environmental assessments of maternal behavior.

Results

Unlike the other adoption studies described in this issue, the CAP is by no means completed. We intend to study this unique sample of children through adolescence and to test them on the same adult battery completed by their parents over a decade and a half earlier. Although we are reticent to publish CAP results until our data set is complete, we have reported some preliminary findings which shall be briefly reviewed in this paper. Our attention will then be devoted to examples of the breadth of analyses that can be conducted using the CAP design. In addition to providing estimates of the importance of genetic and environmental sources of variance, these examples include assessment of environmental effects unbiased by heredity, analyses of genotype-environment interaction and correlation, and longitudinal analyses of change and continuity in development.

Preliminary Findings

In an article that provides details of the CAP design, sample, and measures (DeFries et al., 1981), we reported parent-offspring correlations for cognitive abilities in a sample of 119 adopted and 79 control 1-year-olds. We showed that the CAP biological, adoptive, and control parents are similar with regard to various demographic variables, test reliabilities, cognitive test-score variances and factor structure, and assortative mating. Also, there appear to be no important differences between adoptive and control home environments or between adopted and control infants at 12 months of age. Most important with respect to disentangling genetic and environmental influences, selective placement, the matching of biological and adoptive parents, is negligible for general cognitive abilities, education, and occupation.

We were surprised to find significant parent-offspring resemblance for IQ of parents and Bayley Mental Development Index (MDI) scores of their 1-year-old children for all three parent/child comparisons. This pattern of results suggests that both genetic factors and family environmental influences affect individual differences in Bayley MDI scores at 12 months of age. These results were surprising because of the presumption that parental cognitive measures do not correlate with infant intelligence, as well as the presumed lack of long-term predictability of later IQ from infant intelligence measures. However, closer examination of the literature indicates that these issues are far from resolved for 12-month-olds (see DeFries et al., 1981).

The pattern of results for specific cognitive abilities differs sharply from the result for general cognitive ability. No consistent pattern of correlations was found between any of the specific cognitive abilities of the parents and Bayley MDI scores at 1 or 2 years of age. Although some significant relationships were found for biological parents (e.g., visual memory) or for adoptive parents (e.g., verbal ability), these relationships were not replicated in the control families.

These results have important implications for understanding the nature of infant intelligence. The finding that infant intelligence as measured by the Bayley MDI is correlated with general cognitive ability of the biological parents suggests that there is genetic covariance between infant and adult intelligence. The finding that infant intelligence is correlated only with general cognitive ability of the parents, not with the parents' specific cognitive abilities, suggests that this genetic covariance between infant and adult intelligence involves g, general cognitive ability, rather than specific cognitive processes. These results support the recent revival of attempts to improve the predictiveness of infant tests, particularly those, such as Fagan's (1982) work with the recognition memory paradigm, which appear to tap g.

We have also reported on an intensive study of the communicative development of 50 adopted 1-year-olds using CAP videotape recordings of mother-infant interaction (Hardy-Brown et al., 1981). This study included assessments of prelinguistic vocalization characteristics, gestural communication, imitation, and true-word vocalizations. Numerous parental speech characteristics were also assessed. The results suggested genetic influence on infants' communicative competence: general cognitive ability of biological mothers was significantly correlated with the communicative competence of their adopted-away infants. Although cognitive abilities of the adoptive mothers were not significantly related to the infants' communicative competence, significant relationships were found for two measures of the language-learning environment: maternal imitation of the infant's vocalizations and contingent vocal responsivity of the mother to the infant's vocalizations. We are currently in the process of extending this research by studying 50 control families in which, of course, both genetic and environmental influences should be operative.

Genetic and Environmental Sources of Variance

A major goal of the adoption design is to untangle hereditary and experiential factors that contribute to parent-offspring resemblance by investigating both adoptive relationships, in which family members share the home environment but not heredity, and biological relationships, in which "family" members share heredity but not family environment. In this section, we shall update our previous report of resemblance between parental IQ and Bayley MDI scores at 12 months of age and extend the analysis to data on 2-year-olds in a sample of children tested at both 1 and 2 years of age. This sample includes 152 adoptees, their biological and adoptive parents, and 120 control families. In all analyses, scores 3 SD above or below the mean have been removed so that our results do not depend on rare outliers.

Table 2 describes Bayley MDI means and variances for the adopted and control probands at 12 and 24 months of age. The CAP sample is about half a standard deviation above the mean of the standardization sample. However, at 12 months of age, the standardization sample consisted of only 94 children, 16% of whom were rural and 13% of whom were nonwhite; for 24% of the children, the head of the household had an eighth-grade education or less. With these differences in mind, it again appears that the CAP sample is reasonably representative of the Caucasian, urban-suburban population. Most important, the standard deviations at 24 months are close to the standardization sample standard deviation of 16, although the CAP standard deviations are somewhat lower at 12 months.

TABLE 2

MEANS AND STANDARD DEVIATIONS FOR BAYLEY MENTAL DEVELOPMENT INDEX SCORES AT 12 AND 24 MONTHS FOR ADOPTED AND CONTROL PROBANDS

	N	Mean	SD
One-year-olds:			
Adopted	152	106.0	11.8
Control	120	106.6	12.4
Two-year-olds:			
Adopted	151	107.0	15.0
Control	120	108.0	15.3

Before presenting the parent-offspring data, the issue of selective placement should be considered. Although the effects of selective placement can be incorporated in model-fitting approaches to analysis of adoption data, the clean separation of genetic and environmental influences is attenuated when adoptive parents resemble biological parents. Fortunately, selective placement is negligible in the CAP. The biological mothers' IQ correlates .06 with the adoptive mothers' IQ and .01 with the adoptive fathers' IQ. The biological fathers' IQ correlates .00 and −.10 with the adoptive mothers' and fathers' IQs, respectively. Selective placement for education and occupational status, two indices often used to assess parental IQ indirectly, were also negligible. For education, the median correlation between the biological parents and the adoptive parents was .01; for the grandparents, the median correlation was .06. Median selective-placement correlations of NORC ratings of occupational status were −.16 for parents and −.01 for grandparents.

In Table 3, data for height are reported first because height serves as a familiar "anchor" variable to assess the reasonableness of the results and against which to compare the behavioral data. Height at 12 months of age shows long-range predictability, moderate parent-offspring correlations, and significant heritability in twin studies (Plomin & DeFries, 1981). The parent-offspring correla-

TABLE 3

PARENT-OFFSPRING CORRELATIONS FOR HEIGHT AND MENTAL ABILITY

	Biological				Adoptive				Control			
	Mother		Father		Mother		Father		Mother		Father	
Measure	*r*	*N*	*r*	*N*	*r*	*N*	*r*	*N*	*r*	*N*	*r*	*N*
Height:												
1-year-old height	.36*	132	−.07	25	.01	132	.01	132	.35*	106	.21*	105
2-year-old height	.33*	127	.11	23	.04	126	−.02	127	.24*	96	.24*	96
Average height at 1 and 2 years	.43*	117	.03	21	.05	117	−.02	118	.31*	87	.24*	87
IQ:												
1-year-old MDI	.11	149	.39*	29	.12	149	.12	144	.06	114	.16	115
2-year-old MDI	.09	148	.44*	29	.08	148	.10	143	.22*	114	.15	115
Average MDI at 1 and 2 years	.09	148	.54*	29	.08	148	.10	143	.18*	114	.19*	115

* $p < .05$.

tions for height in the CAP sample verify the expectation of significant genetic influence and no significant family environmental effect. The biological and control correlations are significant, whereas those between adoptive parents and offspring are not. The patterns of correlations are quite similar for the 1- and 2-year-olds, and essentially the same pattern is found when measures of the infants' height at 1 and 2 years are averaged.

Unlike measures of height, tests of mental ability cannot be presumed to measure the same trait in parents and offspring. Thus, these parent-offspring correlations are best viewed as cross-correlations for different characters in the adults and the infants (DeFries, Kuse, & Vandenberg, 1979; Plomin & DeFries, 1979), although the logic of the adoption design remains the same. The cross-correlation between biological parents' IQ and infants' Bayley scores is a function of the heritability of the adult IQ scores, the heritability of the Bayley scores, and the genetic correlation between infant Bayley scores and adult IQ scores. The genetic correlation refers to the extent of overlap between the set of genes that affects infant Bayley scores and the set of genes that influences adult IQ. Thus, cross-correlations between parental and offspring measures can be used to infer the extent to which characters in infancy are related to adult characteristics. More specifically, in an adoption study, a significant cross-correlation between biological parents and their adopted-away infants suggests both that infant and adult IQ scores are influenced by heredity and that the genes that affect infant intelligence to some extent also affect adult IQ.

Table 3 shows no significant correlations between Bayley scores of 12-month-old infants and cognitive ability of their parents, with the exception of the small sample of biological fathers. For 2-year-olds, only the biological father and control mother correlations are significant. When the Bayley MDI scores at 1 and 2 years are averaged in order to increase their reliability, the pattern of parent-offspring correlations remains much the same, although the correlations are significant for both control mothers and fathers. However, statistical significance of the correlations does not tell the whole story. For example, if the true correlation between biological mothers' IQ and infants' Bayley MDI scores is .10, a sample in excess of 600 is required to attain 80% power to detect the correlation (Cohen, 1977). The pattern of correlations for mental ability, unlike that for height, is consistent with the hypothesis of some effect of the family environment (the adoptive parent correlations are all about .10) and some hereditary influence (the biological mother correlation is about .10). As we would expect, given a biological parent correlation of .10 and an adoptive parent correlation of .10, the correlations for the control parents are about .20. The results of model-fitting procedures, discussed later, support this interpretation.

Environmental Effects Unbiased by Heredity

It is our conviction that behavioral genetic approaches to the study of development are as useful for studying the effects of environment as for studying heredity. One example is that environmental assessments embedded in an adoption design permit analyses of environmental influence free of genetic bias. In addition, such a study can provide estimates of the extent to which supposedly environmental influences are in fact mediated by heredity—information of considerable importance when it comes to thinking about intervention.

The role of parental behavior in infant cognitive development has been studied for at least 40 years, but it is only within the last decade that standardized measures of the home environment have been constructed. One of the most frequently employed instruments is the HOME inventory (Caldwell & Bradley, 1978), which uses observations and interviews in the home to assess maternal responsiveness and involvement, variety of stimulation, provision of play materials, organization of the environment, and discipline. The HOME is significantly correlated with Bayley mental scores in infancy and predicts later IQ as well (e.g., Bradley, Caldwell, & Elardo, 1979; Elardo, Bradley, & Caldwell, 1975; Stevenson & Lamb, 1979). However, nearly all previous reports concerning the relationship between measures of the home environment and children's intelligence have been based on studies of families in which both heredity and environment are shared by parents and their offspring.

As long as heredity and environment are confounded, putative environmental relationships might well be mediated genetically. Consider, for example, the possibility that home environmental indices are substantially correlated with parental IQ, as suggested by Longstreth, Davis, Carter, Flint, Owen, Rickert, and Taylor (1981). If measures of the home environment are merely a roundabout way of measuring parental IQ, then the genetic hypothesis looms large in the interpretation of correlations between home environmental measures and children's IQ. The point is that, in the absence of selective placement, environmental relationships discovered in adoptive homes estimate environmental effects free of genetic confounds. Also, the difference between presumed environmental relationships in control homes and those observed in adoptive homes provides an estimate of the extent of genetic involvement in such relationships.

The HOME Responsivity and total scores were used to address this issue. The HOME (Caldwell & Bradley, 1978) consists of 45 items, of which two-thirds are based on observations in the home and the remainder on parental interviews. Means and standard deviations are presented in Table 4. Once again, the adoptive and control families are quite similar in terms of both means and variances. These means are higher and the standard deviations lower than those reported in the HOME manual; however, the latter data were derived from a lower-class sample of 174 Arkansas families (66% black, 34% on welfare, and 29% with an absent father). The CAP results are in agreement with reports of other middle-class samples (Hollenbeck, 1978; Ramey, Mills, Campbell, & O'Brien, 1975). The HOME is extremely limited in assessing middle-class homes when the standard dichotomous scoring is used. For example, ceiling effects are severe (DeFries et al., 1981) and variance is restricted (for seven of the items, more than 95% of the CAP families had the same score). The HOME Responsivity scale was used because it shows better psychometric characteristics and also yields the strongest relationships to infant mental ability in the CAP and in another study of middle-class children (Stevenson & Lamb, 1979). We are currently attempting to develop psychometrically stronger scales based on the HOME items and are using quantitative scoring in order to capture more variability in middle-class homes.

TABLE 4

Means and Standard Deviations for Home Observations for the Measurement of the Environment (HOME) Responsivity and Total Scores at 12 and 24 Months for Adoptive and Control Families

	N	Mean	SD
One-year home visit:			
Adoptive:			
HOME Responsivity..	143	9.0	1.3
HOME total.........	141	38.7	2.8
Control:			
HOME Responsivity..	119	9.3	1.0
HOME total.........	117	38.6	3.0
Two-year home visit:			
Adoptive:			
HOME Responsivity..	151	9.5	1.1
HOME total.........	149	39.8	2.3
Control:			
HOME Responsivity..	120	9.3	1.1
HOME total.........	119	39.6	2.3

Table 5 presents correlations between HOME scores and Bayley MDI scores at 1 and 2 years of age for the adoptive and control samples. Most noteworthy is the finding that the HOME measure of maternal responsiveness in adoptive homes is significantly correlated with Bayley MDI scores at both 1 and 2 years. The fact that the Responsivity scale predicts better than the total score probably reflects psychometric problems with the HOME, as described above. Thus, for the first time, we may conclude that at least part of the widely reported relationship between HOME scores and IQ is indeed environmental. Second, for 1-year-olds, the correlation in the control families is similar to that in the adoptive families, suggesting that genetic factors are not importantly involved in the relationship between HOME measures and infant MDI scores, although it is nonetheless possible that both adoptive and control parents are responding to genetic differences among their children (see Scarr & McCartney, in this issue). However, for 2-year-olds, the correlations in the control families are greater than those in the adoptive families (the difference is significant for the total HOME scores). This suggests that the relationship between HOME and MDI scores for 2-year-olds is partially mediated by hereditary

TABLE 5

Correlations between HOME Measures and Bayley MDI Scores at 12 and 24 Months for Adoptive and Control Samples

	Adoptive Families		Control Families	
	r	*N*	*r*	*N*
One-year-olds:				
HOME Responsivity..	.18*	143	.16	119
HOME total.........	.09	141	.14	117
Two-year-olds:				
HOME Responsivity..	.22*	150	.39*	120
HOME total.........	.15	148	.38*	119

* $p < .05$.

factors. The fact that the correlations are of borderline significance in the adoptive homes does suggest that some of the relationship between the HOME and the Bayley MDI is mediated via family environment as well.

One likely possibility, alluded to earlier, is that the HOME measure may be related to some parental characteristic, such as IQ, which in turn is related to infant mental ability. In light of the above findings, it is possible that this relationship is genetically mediated. A recent study suggests that the relationship between an environmental index and IQ scores of older children disappears when maternal IQ is partialed out of the relationship (Longstreth et al., 1981). Table 6 shows the correlations between HOME measures and parental IQ scores. HOME scores, particularly for the second-year home visit, are significantly correlated with parental IQ. When parental IQ was partialed out of the relationship between HOME and Bayley MDI scores, the associations reported in Table 5 changed very little, less than .04, for both the adoptive and control families. Thus, contrary to the results for older children as reported by Longstreth and coauthors, we do not find that the relationship between HOME and Bayley MDI scores is mediated by parental IQ, even though parental IQ shows some relationship to HOME scores. This interpretation is buttressed by our model-fitting path analyses which are discussed in the following section.

Path Models and Maximum-Likelihood Estimates of Genetic and Environmental Parameters

We have just presented examples of basic parent-offspring and environment-offspring correlations related to infant mental development in the CAP sample. Although we discuss genetic influence and environmental influence in terms of correlations observed in the adoptive and nonadoptive families, estimating genetic and environmental components of variance is hazardous when the results are considered in this piecemeal manner.

A more powerful estimation procedure utilizes path models and the simultaneous analysis of data on the adoptive, biological, and control parents and their children, as well as an environmental index. Model-fitting approaches are particularly useful because, in addition to analyzing all of the data simultaneously, they make assumptions explicit and permit tests of the relative fit of different models.

With the help of David Fulker of the Institute of Psychiatry, University of London, we have developed path models and have applied maximum-likelihood estimation procedures to the CAP data. A path model incorporating general cognitive ability of adults, Bayley MDI scores of children, and HOME Responsivity supported our earlier interpretation of the results: at both 1 and 2 years of age, genetic and environmental influences were both significant, although the environmental influence of parental scores appears to be mediated primarily through the environmental index, HOME Responsivity (Fulker & DeFries, Note 2). Model-fitting procedures are amenable to both multivariate and longitudinal extensions. An example of a longitudinal model-fitting approach to analysis of the CAP data on 1- and 2-year-olds is included in this issue (Baker, DeFries, & Fulker, in this issue).

Genotype-Environment Interaction

Genotype-environment interaction refers to the possibility that individuals of different genotypes may respond differently to environ-

TABLE 6

CORRELATIONS BETWEEN HOME MEASURES AND PARENTAL IQ FOR ADOPTIVE AND CONTROL FAMILIES

	ADOPTIVE PARENTS' IQ				CONTROL PARENTS' IQ			
	Mother		Father		Mother		Father	
	r	*N*	*r*	*N*	*r*	*N*	*r*	*N*
One-year home visit:								
HOME Responsivity..	−.02	140	.14	135	.12	113	.06	114
HOME total.........	.16*	138	.25*	113	.26*	111	.13	112
Two-year home visit:								
HOME Responsivity..	−.01	148	.21*	143	.21*	114	.06	115
HOME total.........	.18*	146	.31*	141	.29*	113	.08	114

* $p < .05$.

mental factors. This quantitative genetic definition of genotype-environment interaction is thus quite different from the frequently expressed notion that the threads of experience and heredity are so completely interwoven that they cannot be untangled. Plomin et al. (1977) discussed these issues and proposed using adoption data in a test of genotype-environment interaction which provides a tool for isolating environmental influences that differentially affect individuals who differ genetically.

A 2 × 2 analysis of variance design, as described by Plomin et al. (1977), is the easiest to understand. We can study Bayley MDI scores of adoptees whose biological mothers were above or below the mean for general cognitive ability in order to evaluate the "main effect" of genotype. That is, if genetic factors influence infant intelligence, then adoptees whose biological mothers showed above average IQ should, on the average, have higher Bayley scores than adoptees whose biological mothers' IQs were below average. Similarly, the adoptive mothers' IQ can be used to evaluate the main effect of family environment as indexed by parental IQ. A significant interaction would indicate that the environmental effect of parental intelligence on their infants' intelligence depends on the genetic propensities of their children; or, conversely, that children of different genetic predispositions respond differentially to the family environment. The 2 × 2 analysis of variance suggested main effects for genotype and environment as expected from the parent-offspring correlations presented in Table 3. However, no evidence for genotype-environment interaction emerged at 12 or 24 months: the two-way interactions between biological mothers' IQ and adoptive mothers' IQ as these variables affect adoptees' Bayley scores were not significant.

Of course, adoptive mothers' IQ is not likely to be the most sensitive indicator of a family environment conducive to cognitive development of infants. For this reason, we repeated the analysis, using HOME Responsivity scores as the environmental measure. Again, the genotype-environment interactions were not significant. Although it is certainly possible that other environmental measures might reveal significant interactions between genetic and environmental factors, it is noteworthy that this first attempt to assess the effects of genotype-environment interaction on cognitive development found no significant interaction.

This procrustean 2 × 2 design is only illustrative. A more powerful approach is the use of hierarchical multiple regression to analyze the same variables in a continuous rather than dichotomous manner (see Plomin et al., 1977). The results of such hierarchical multiple regression analyses of the CAP data were similar to those described for the dichotomous 2 × 2 analyses of variance.

Genotype-Environment Correlation

Genotype-environment interaction refers to the differential effect of an environmental variable on individuals who differ genetically. Genotype-environment correlation, on the other hand, refers to the differential exposure of genotypes to environments. Plomin et al. (1977) proposed three types of genotype-environment correlation: *passive,* in which nonadoptive parents give their children both genes and an environment that are favorable (or unfavorable) for the development of a trait; *reactive,* in which people may react differently to children of different genotypes; and *active,* in which children actively seek environments related to their genetic propensities.

Considerable attention has been focused on the issue of genotype-environment correlation as it affects quantitative genetic analyses. However, the topic is also worthy of study in its own right. For example, reactive and active genotype-environment correlations are relevant to the issue of direction of effects in socialization; that is, whether parents affect their children's development, or whether parental behavior reflects their children's inherent tendencies. The presence of genotype-environment correlation of the reactive type would suggest that parental child-rearing behavior is a response to genotypic differences among children rather than a cause of the observed differences. Sandra Scarr has fashioned a general theory of development around the concept of genotype-environment correlation, suggesting that development during childhood is marked by a shift from the passive type of genotype-environment correlation to the reactive and, especially, the active type (Scarr & McCartney, in this issue).

Adoption studies can be used to assess the magnitude of passive genotype-environment correlation. Because this type of correlation is one component contributing to phenotypic variance, the variance for adopted children should be less than that for control children if passive genotype-environment correlation is important, since adoptees do not share both heredity and environment with their adoptive parents. Although results based on this test have been interpreted as suggesting substantial passive genotype-environment correlation (e.g., Jencks, 1972), it is not a strong test because restriction of range for adoptees could also explain the lesser variance of their scores in studies in which the representativeness of the biological parents is unknown. Demographic data described earlier for the CAP sample suggest that the biological parents in this study are reasonably representative.

In the CAP sample, the standard deviations of the Bayley MDI scores of the adoptees and controls at 12 months of age are 11.8 and 12.4, respectively; at 24 months, the standard deviations are 15.0 and 15.3. Although the variance for the adoptees is slightly less than for the controls, the differences are not significant with samples of this size. Thus, there appears to be a small effect at most of passive genotype-environment correlation on differences in mental ability among the CAP probands at 1 or 2 years of age. Maximum-likelihood analyses of path models of these data also find little evidence for passive genotype-environment correlation (Fulker & DeFries, Note 2).

Although discussions of genotype-environment correlation usually concentrate on the passive type, the reactive and active varieties are more interesting and are likely to be more important. Plomin et al. (1977) proposed a test of reactive and active genotype-environment correlation that simply involves investigating the correlation between any measurable aspect of the environment of adoptees and some trait measured in their biological parents. For example, if adoptive parents' HOME scores reflect genetic differences relevant to mental ability of adopted children, HOME scores from these adoptive homes would be expected to be correlated with intellectual ability of the biological parents (which is a "genotypic" estimate of the adoptees' ability). In the absence of selective placement (i.e., a significant correlation between adoptive and biological parents), this test will detect genotype-environment correlation only when there is a heritable relationship between the phenotypes of the biological mother and the adopted child and when there is a relationship between the environmental measure and the adopted child's phenotype. Although these appear to be quite restrictive limitations, they really define genotype-environment correlation: genetic differences among children are correlated with differences among their environments.

At this stage, because of the dearth of instruments to measure the infant's active interaction with the environment (Wachs & Gruen, 1982), we can actually investigate only the reactive type of correlation. As an example of such a test, we examined the relationship between HOME scores in the adoptive families and cognitive ability of the biological parents. Although Bayley MDI scores of adoptees were related to biological parents' general cognitive ability (suggesting genetic influence) and also to HOME scores in the adoptive homes (suggesting environmental influence), no significant correlations were found between general cognitive ability of the biological parents and the HOME total or Responsivity scores recorded during the 1- or 2-year-old visits to the adoptive homes (see Table 7). It is interesting, however, that the correlations are all negative. If this finding is authentic, it suggests negative genotype-environment correlation of the reactive type: adoptive parents are more responsive to adoptees whose biological parents have lower IQs. Although it is commonly assumed that genotype-environment correlation is positive, negative genotype-environment correlation may also occur (Plomin et al., 1977).

There are two reasons why one cannot conclude from this analysis that reactive genotype-environment correlation is unimportant in cognitive development. First, the present sample size is sufficient to detect only substantial effects; the analysis has 80% power only if the correlation between the environmental measure and the biological parents' score is greater than .20. Second, different combinations of environmental measures, children's behaviors, and biological parents' mea-

TABLE 7

GENOTYPE-ENVIRONMENT CORRELATION: CORRELATION BETWEEN BIOLOGICAL PARENTS' IQ AND HOME SCORES IN ADOPTIVE HOMES

	BIOLOGICAL MOTHERS' IQ		BIOLOGICAL FATHERS' IQ	
	r	*N*	*r*	*N*
One-year home visit:				
HOME Responsivity. .	−.16	113	−.21	25
HOME total.	−.12	87	−.39	17
Two-year home visit:				
HOME Responsivity. .	−.04	120	−.02	20
HOME total.	−.05	83	−.21	13

sures might yield evidence of significant genotype-environment correlation.

Longitudinal Analyses of Genetic and Environmental Contributions to Change and Continuity in Development

Beginning with Francis Galton's original twin study in 1875, the earliest human behavioral genetic studies focused on development. It is critically important for developmentalists to realize that the expression of genes, as well as the environment, can change during development.

Examples of two types of longitudinal analyses will be considered. First, we can longitudinally extend the environmental analyses discussed earlier by predicting later outcomes from earlier environmental assessments using genetic controls provided by the adoption design. Second, we can partial out genetic and environmental influences from a longitudinal correlation in order to identify sources of developmental continuity.

Longitudinal environmental analyses.— Concerning the longitudinal extension of the environmental analyses discussed earlier, we can study the effect of early environmental influences in adoptive homes on later behavioral outcomes without the usual genetic confounds that occur when parents and their children share heredity as well as family environment. By comparing these data from adoptive families to data from control families, we can also identify any genetic involvement in such longitudinal environmental relationships. The correlation between HOME Responsivity in the adoptive families assessed at 12 months and Bayley MDI scores at 24 months was .20 ($p < .02$). This significant correlation suggests that the ability of the HOME to predict later IQ is mediated environmentally. In the control families, the correlation was .14 ($p > .05$). Although our earlier analyses (see Table 5) showed genetic as well as environmental influence on the contemporaneous association between HOME measures and Bayley MDI scores, the fact that the longitudinal correlation in the control families is no larger than in the adoptive families suggests that genetic factors may not be involved in the predictive ability of the HOME. This type of longitudinal environmental analysis can be extended to a multivariate framework in order to encompass the diverse environmental measures included in the CAP.

Etiology of developmental continuity.— The second type of longitudinal analysis is focused on the etiology of continuity in development. As explained earlier, developmental stability can be affected by both environmental and genetic factors. If continuity in Bayley MDI scores from 12 to 24 months is mediated genetically, we would expect the longitudinal correlation to be reduced when the effect of biological mothers' IQ—an estimate of genotype—is removed from the longitudinal correlation. Similarly, we can ask whether environmental influences underlie the observed continuity in the Bayley scores in infancy. However, genotype as estimated by biological parents' IQ and environment as indexed by IQ of the adoptive parents and HOME Responsivity are by no means perfect estimates of the adoptees' genotypes or environments. Biological mothers' IQ will not provide an estimate of genotypic value at all if genetic factors affecting infant Bayley scores are not related to genetic factors that affect adult IQ. Furthermore, the genetic estimate is weakened by the fact that parents and their offspring share only half of the additive genetic variance. Similarly, environmental factors other than HOME Responsivity, including idiosyncratic experiences, could provide an environmental basis for longitudinal stability of the Bayley scores. Nonetheless, it is instructive to ascertain the extent to which these genotypic and environmental estimates are responsible for the stability of Bayley MDI scores in infancy.

Before discussing the results for the Bayley scores, it is useful for didactic purposes to describe the results for height. The zero-order correlation for height from 12 to 24 months is .44 for the adopted probands. Partialing out biological mothers' height reduced the longitudinal correlation only slightly, from .44 to .36, suggesting that genetic factors indexed by biological mothers' height may mediate continuity for height in infancy to some slight degree. Removal of the effects of maternal height produced a similar reduction in the longitudinal correlation in the control families, which would be expected if genetic factors are involved in stability. Not surprisingly, partialing out adoptive parents' height did not affect the longitudinal correlation.

For the Bayley MDI, the longitudinal correlation between 12 and 24 months is .47 for the adopted probands. Partialing out the biological mothers' IQ from the longitudinal correlation had virtually no effect (partial correlation of .46), suggesting that this genotypic estimate of the children's IQ is not responsible for continuity in Bayley MDI scores. This result has been verified by the maximum-likelihood analysis of a longitudinal path model of these data reported by Baker et al. (in this issue). Neither of the environmental indices, adoptive parents' IQ and HOME Responsivity, was related to longitudinal stability of the Bayley scores. Corresponding analyses of data for the control families also yielded no significant effects. Thus, estimates of genotypic values based on biological mothers' IQ are not related to stability of Bayley scores in infancy, nor do our environmental measures underlie the observed continuity.

Discussion

Every analysis described in this report examines environmental as much as genetic variation. We have shown how the adoption design can be used to estimate the magnitude of family environmental variance, to identify specific environmental effects free of genetic bias, to isolate environmental influences that affect some individuals but not others (genotype-environment interaction), and to assess the extent to which children create their own environments (genotype-environment correlation). These examples of analyses made possible by the CAP design support our conviction that human behavioral genetic methodologies will serve equally to enhance our understanding of environmental influences and to increase our appreciation of the importance of genetic variance.

We have found few exceptions to the rule that individual differences in infant intelligence are not explainable. However, this lack of ability to explain differences in cognitive ability among infants is not surprising. As has been pointed out by McCall (1981), individual differences in infant mental development at a given age are due primarily to differences in developmental rate and may be small compared to the dramatic developmental changes that take place in nearly all infants from age to age. Furthermore, McCall's "scoop" model of development suggests that development in infancy is highly canalized so that genetic and environmental deviations do not make much of a difference. Canalization loosens its grip on development after infancy, thus permitting genetic and environmental influences to have differential effects on developmental processes.

The analyses discussed in this report are merely examples of the types of analyses that can be conducted using the CAP design and data set. Other parental and infant behaviors, as well as other environmental influences, can be studied. Temperament, for example, is not likely to fit McCall's "scoop" model of development and may thus show more interesting variation in infancy. Likewise, communicative development in infancy has shown greater predictive association with later intelligence than do most other measures, and may be a particularly promising area for behavioral genetic research (Hardy-Brown, in press). Multivariate approaches can also be employed in the search for explanatory power. The CAP, with its representative sample of adoptive and matched control families and negligible selective placement, will show its true worth in the future as its sample size increases, as the probands grow older, and as data on younger siblings of the probands are included in the analyses.

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